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TITLE OF THE INVENTION

METHOD AND SYSTEM FOR COMPENSATING FOR WHEEL WEAR ON A TRAIN

This application is a Continuation-In-Part of application Serial No. 10/157,874, filed May 31, 2002, now allowed, the entirety of which is incorporated herein by reference, and a Continuation-In-Part of application Serial No. 10/609,377, filed July 1, 2003, the entirety of which is also incorporated by reference herein.

BACKGROUND OF THE INVENTION

Field of the Invention

The invention relates to railroads generally, and more particularly to a system and method for determining wheel size to compensate for wheel wear.

Discussion of the Background

Controlling the movement of trains in a modern environment is a complex process. Collisions with other trains must be avoided and regulations in areas such as grade crossings must be complied with. The pressure to increase the performance of rail systems, in terms of speed, reliability and safety, has led to many proposals to automate various aspects of train operation. For example, positive train control (PTC) and automatic train control (ATC) systems have been widely discussed in recent years.

Some automated systems rely on global positioning system (GPS) receivers for indications of train speed and position (as used herein, “global positioning system” and “GPS” refer to all varieties of global positioning system receivers, including, but not limited to, differential global positioning system receivers. Still other systems use inertial navigation systems (INSs) for determining speed and location. However, GPS receivers and INSs sometimes fail, and for that reason it is desirable to have a back-up system.

One method that can be used in case of a positioning system failure is to measure the rotation of motor, axle or wheel rotation to determine the speed at which a train is traveling and/or the distance which a train has traveled. Each time the wheel makes a compete revolution, the distance traveled by the wheel is equal to its circumference in the absence of any slippage. Thus, if the radius R of the wheel is known, the distance traveled for each revolution of the wheel is equal to $2\pi R$. However, the radius of a wheel changes over time due to wheel wear. For example, a standard train wheel can decrease in size from 40 inches to 36 inches over its useful life. Therefore, the distance traveled in each wheel revolution can vary between 125.7" and 113.1", a difference of approximately 12.6" or 10%. This error is significant.

What is needed is a method and system that compensates for wheel wear.

SUMMARY OF THE INVENTION

The present invention meets the aforementioned need to a great extent by providing a method and system for compensating for wheel wear in which wheel rotation information from a revolution counter or a tachometer and position and/or

speed information from an independent positioning system such as GPS or INS are measured over a predetermined distance and used to determine the size of the train wheels. This process is performed periodically to compensate for wheel wear.

In one aspect of the invention, the system includes a map database and the position information from the independent positioning system is used to as an index to ensure that the rotation data used for the speed/position comparison between the position system and rotation data is collected in an area of straight and flat track so as to exclude errors in the rotation data caused by wheel slippage and turns.

In another aspect of the invention, the data used for the comparison between the speeds/distances indicated by the positioning system and by the rotation data is collected over a long distance to minimize known errors in the positioning system. In yet another aspect of the invention, a total distance traveled is calculated using an integration technique by adding a plurality of linear differences in successive positions reported by the positioning system over short periods of time. This technique is particularly advantageous when performed over curved sections of track.

In another aspect of the invention, information from the positioning system is compared to information from the wheel sensor to calculate a correction factor which can be used to correct information supplied by the wheel sensor for wheel wear. In some embodiments, the correction factor is calculated by calculating an actual wheel size and comparing the calculated actual wheel size to the nominal wheel size. In other embodiments, the correction factor is calculated independently of the wheel size by comparing speed and/or distance indicated by the wheel sensor

(using the nominal wheel size) with speed and/or distance from a positioning system.

BRIEF DESCRIPTION OF THE DRAWINGS

A more complete appreciation of the invention and many of the attendant features and advantages thereof will be readily obtained as the same become better understood by reference to the following detailed description when considered in connection with the accompanying drawings, wherein:

Figure 1 is a logical block diagram of a train control system according to one embodiment of the invention.

Figure 2 is a flowchart showing a wheel wear compensation technique according to one embodiment of the invention.

Figure 3 is a logical block diagram of a train speed signal distribution system according to another embodiment of the present invention.

Figures 4(a) and 4(b) are, respectively, schematic drawings of distance calculated by a linear method and an integration method according to an embodiment of the present invention.

Figure 5 is a flowchart of a wheel wear compensation technique employing the integration method of Figure 4(b) according to an embodiment of the invention.

Figure 6 is a flowchart of a technique for calculating a correction factor for a wheel sensor according to an embodiment of the present invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

The present invention will be discussed with reference to preferred embodiments of train control systems. Specific details, such as wheel sizes and types of positioning systems, are set forth in order to provide a thorough understanding of the present invention. The preferred embodiments and specific details discussed herein should not be understood to limit the invention.

Referring now to the drawings, wherein like reference numerals designate identical or corresponding parts throughout the several views, Figure 1 is a logical block diagram of a train control system 100 according to the present invention. The system 100 includes a control unit 110, which typically, but not necessarily, includes a microprocessor. The control unit 110 is connected to a revolution counter 120. The revolution counter 120 measures rotation of a locomotive wheel (not shown in Fig. 1) on a train. The revolution counter 120 may be of any type, including mechanical, magnetic, and optical. The revolution counter 120 may measure the rotation of a wheel directly, or may measure rotation of an axle to which the wheel is connected, or may measure rotation of a motor driveshaft or gear that powers the wheel.

Also connected to the control unit 110 is a positioning system such as a GPS receiver 130. The GPS 130 receiver can be of any type, including a differential GPS receiver. Other types of positioning systems, such as inertial navigation systems (INSs) and Loran systems, can also be used. [As used herein, the term "positioning system" refers to the portion of a positioning system that is commonly located on a mobile vehicle, which may or may not comprise the entire system. Thus, for example, in connection with a global positioning system, the

term "positioning system" as used herein refers to a GPS receiver and does not include the satellites that are used to transmit information to the GPS receiver.] The GPS receiver 130 provides position and speed information to the control unit 110.

The control unit 110 uses the position information from the GPS receiver 130 as an index into a map database 140. The map database 140 provides information including track grade and curvature to the control unit 110. As will be explained in further detail below, this information is used in some embodiments to ensure that rotation information from the revolution counter will not include rotation information that is corrupted due to wheel slippage and/or errors due to track curvature.

Referring now to Fig. 2, a flowchart 200 illustrates operation of a wheel wear correction method according to one embodiment of the present invention. The control unit 110 determines whether track conditions are acceptable at step 210. In some embodiments, this is accomplished by obtaining the current position from the GPS receiver 130 and indexing the map database 140 to determine the track grade and curvature over a predetermined length of upcoming track over which rotation information is to be collected.

The predetermined length of track is preferably of a sufficient length such that any errors introduced by the inaccuracy of the global positioning system receiver 130 are minimized. Obviously, it is advantageous to use as great a length as possible since the effect of positioning systems errors are decreased as the length is increased. However, there is a trade-off that must be made because if the length is too great, the time required to complete the wheel correction algorithm is too

long and/or the amount of curvature and grade in the track segment over which the data is to be taken preclude running the algorithm over too much track in the system. In some embodiments, the predetermined length of track is 100,000 meters. In such an embodiment, with a global positioning system having a position error on the order of 30 meters, the total error is equal to (30 + 30)/100,000 = .0006 = .06%.

In the embodiment described by Fig. 2, the determination as to whether track conditions are acceptable is made at the start of the algorithm. In other embodiments, rotation data is only collected if the train is traveling greater than some minimum. The reason behind this is that most wheel slippage occurs at slow speeds as a locomotive is attempting to accelerate. Most locomotives use electric induction motors, and most electric motors used in locomotives have torque curves with torques decreasing as speed increases such that it is not possible for the locomotive to generate enough torque to cause the wheels to slip above certain speeds. In some embodiments, the minimum speed at which data will be collected is 15 m.p.h.; in other embodiments, the minimum speed is 20 m.p.h.

In yet other embodiments, the wheel acceleration is monitored to detect wheel slippage. If an acceleration exceeds a threshold, the collected information is discarded and the entire process is started over.

In still other embodiments, the system notes the upcoming sections of the track in which either the grade or curvature is above a corresponding threshold and does not include those distances and any corresponding rotation information collected over those distances in the calculations. Such embodiments are

particularly useful for railroads in which long, straight and level sections of track are not present in many areas.

If the track conditions are not favorable at step 210, the system delays for a period of time at step 220 and repeats step 210 until track conditions are favorable. When track conditions are favorable at step 210, the control unit 110 determines a start position from the global positioning receiver 130 at step 230 and counts rotations as measured by the revolution counter 120 at step 240. When a threshold (which may be a number of rotations and/or a time period) has been reached at step 250, the control unit 110 determines a stop position from the global positioning receiver 130 at step 260. Next, at step 270, the control unit 110 calculates the distance D traveled based on the start and stop positions measured at steps 230 and 260, respectively. Then the control unit 130 determines the radius R of the wheel at step 280 according to the equation $R = D/2\pi T_r$, where T_r is the total number of rotations counted over the distance D. The control unit 110 then delays, at step 290, for a period of time such as a day (it is not necessary to run the algorithm often as train wheels wear slowly).

In the above-discussed embodiments, a predetermined distance is used. It should be noted that the predetermined distance will vary depending upon the accuracy of the positioning system used and the particular environment in which the invention is used.

In the foregoing embodiments, data is not collected when the system determines that track conditions are not favorable. However, in cases where curvature exceeds the threshold, it is also possible to allow data collection to occur and correct the data for the curvature.

In another embodiment of the invention, an integration technique is utilized to correct for track curvature. In this technique, the total distance traveled is determined by adding linear differences between positions reported by the positioning system at a plurality of short intervals. In this manner, the sum of linear distances closely approximates the actual "track distance" (the actual distance traveled by the train over the track). Consider the examples shown in Figs. 4(a) and 4(b), which illustrate a section of track 400 between two points A and B. In Fig. 4(a), a linear distance D_o between points A and B is illustrated. This distance D_o is obviously less than the actual track distance between points A and B. In Fig. 4(b), several linear distances $D_{1\text{-}9}$ between a plurality of intermediate points $I_{0\text{-}9}$ are calculated. The sum of these linear distances $D_{1\text{-}9}$ is a much closer approximation of the track distance between points A and B. As the distance between the intermediate points $I_{0\text{-}9}$ decreases, the approximation of the actual track distance becomes more accurate.

Fig. 5 illustrates a flow chart 500 of the steps performed by the control unit 110 in an embodiment employing this integration technique. The revolution counter 120 is reset to zero at step 502 (in other embodiments, the revolution counter is simply read at step 502). The position is then obtained from the positioning system 130 at step 504 and temporarily stored as the last position at step 506. The control unit 110 then delays for a period of time at step 508. As discussed above, the shorter the period is, the more accurate the approximation will be. In preferred embodiments, the period is one second.

After the delay at step 508, the control unit 110 again obtains the current position at step 510. Next, the linear difference between the current position and

the temporarily stored last position is calculated at step 512 and the difference is added to a total distance at step 514.

If the total distance does not exceed a threshold at step 516, steps 506 et seq. are repeated. As discussed above, the selection of the threshold involves a tradeoff. Again, a threshold of 100,000 meters is used in some embodiments.

If the threshold is exceeded at step 516, the revolution counter is read at step 518. The wheel circumference is then calculated by dividing the total distance by the number of revolutions from the revolution counter 120.

In the embodiment described above, the periods of time during which the total distance was traveled were contiguous such that one period began as soon as a previous period ended. This simplified the method by eliminating the necessity of reading the revolution counter at the beginning and end of each period. Those of skill in the art will recognize that it is not necessary for the periods to be contiguous and that the invention may also be practiced by using a plurality of non-contiguous periods and reading the revolution counter at the beginning and end of each period (or, alternatively, resetting the revolution counter at the beginning of each period).

In the foregoing embodiments, positional inputs from the positioning system are used; however, it will be readily apparent that speed can also be used. For example, if the current speed S of the train is known from the positioning system, then the wheel size can be determined according to the equation $S = DF_r = 2\pi RF_r$, where D is the distance traveled in each rotation, F_r is the rotation frequency of the wheel, and R is the radius of the wheel. In practice, the speed from the global positioning system may be read a number of times and the wheel size

corresponding to each reading may be averaged. It should be noted that using speed rather than position information allows the wheel size to be determined more rapidly than using position information and is therefore preferable when wheel size is needed quickly (such as when a gross error has been detected). However, using position information, especially over a long distance, results in greater accuracy. Accordingly, in some embodiments, speed is used to rapidly generate an initial estimate and position is used to generate a better estimate at a later time.

Furthermore, while track curvature and grade were determined by referencing a map database in the embodiments discussed above, it will be readily recognized by those of skill in the art that curvature and grade can be determined from altitude and direction information provided by the global positioning system. For example, the track curvature may be determined by recording the train's position as reported by the positioning system at several times during the period in which data is collected. This position information can be used to construct a curvature profile so that the amount of curvature can be determined after the data is collected. If the curvature is greater than a threshold, the data can be ignored, or, in some embodiments, can be corrected for the curvature such as by using the integration technique discussed herein. The same techniques can be used to construct a grade profile.

It should also be noted that the invention may be incorporated into various types of train control systems, including the aforementioned PTC and ATC systems as well as many others.

In another embodiment of the invention, the wheel wear compensation method is incorporated into a wheel revolution sensor signal distribution/

conversion system such as the QUIP™ system manufactured by the assignee of the present invention, Quantum Engineering. There may be several systems on board a train that input a signal representative of the wheel rotation and use that signal to calculate speed. For example, many locomotives that have been retro-fitted with a train control system also are equipped with a separate speed display. Such systems typically require the conductor/engineer or maintenance personnel to measure the diameter of the train wheel to which the wheel sensor is attached and set DIP switches or otherwise configure the devices to indicate the wheel size. Because the wheel size changes over time as discussed above, these other devices must be reconfigured on some periodic basis, thereby increasing labor costs.

Because there may be several systems that require the wheel sensor signal which together constitute a larger electrical load than the wheel sensor is capable of handling, and because some of these systems require an input signal of a different form than is supplied by the wheel sensor, signal conversion/distribution systems such as the aforementioned QUIP™ distribution/conversion system have been devised. A substantial savings can be realized by modifying these distribution/conversion systems to output a modified signal that is representative of a wheel sensor signal would be generated by a wheel of a fixed size. Thus, for example, if the conversion/distribution system outputs a modified wheel sensor signal that is representative of a 40 inch wheel, each of the other systems that use the wheel sensor signal could be configured once for a 40 inch wheel and would thereafter not need to be periodically reconfigured.

Such a conversion/distribution system 300 is illustrated in Fig. 3. The system includes a control unit 110 connected to a wheel revolution sensor 320. In

some embodiments, the wheel sensor 320 outputs a square wave, with each rising edge representing a revolution of the wheel. Thus, the time between leading edges represents the time taken for one full revolution of the wheel. It will be readily understood that the signal output by the wheel sensor 320 may be of many forms, analog or digital, and that the particular form of the signal is not important. Also connected to the control unit 110 is a GPS receiver 130 and a map database 140. The control unit 110 is configured to determine the wheel size using the method described in Fig. 2 or one of the other methods described herein. The control unit 110 determines the speed of the train, which can be taken from the GPS receiver 130 or can be determined with the knowledge of the previously determined wheel size. Using the actual speed of the train, the control unit 110 then determines the parameters necessary for a signal that would be representative of the signal that would be generated by the wheel sensor 320 if the wheel were a predetermined size such as 40". For example, where the wheel sensor outputs a square wave signal as discussed above, the period of the square wave when the train is traveling 30 m.p.h. would be the distance traveled by one revolution, $2*\pi*20$ inches, divided by the train speed, 30 m.p.h. or 528 inches/sec, which is equal to $125.7/528 = .238$ seconds. This .238 second period is supplied by the control unit 110 to a signal generator 180, which generates a square wave of the type discussed above with a period of .238 seconds. The signal generated by the signal generator 180 is then supplied to other systems A, B and C 191-193. Because the signal output by signal generator 180 will always be representative of a 40 inch wheel, it is not necessary to reconfigure the other systems 191-193 once they have been configured for a 40

inch wheel, thereby substantially reducing labor costs associated with these operations.

In the embodiment discussed above, speed is determined as part of the process of determining the parameters of the signal to be generated by the signal generator 180. It will be readily apparent to those of skill in the art that the parameters can be determined without actually calculating the speed. For example, once the wheel size is determined using the method of Fig. 2, that wheel size can be used to form a ratio of the predetermined wheel size to the actual wheel size. Thus, for example, if the predetermined wheel size is 40 inches, and the actual wheel size is 36, the ratio would be 40/36. The control unit can then measure the period of the square wave and multiply the period by the ratio to determine the period of the signal that would be generated by the wheel sensor 320 if the wheel were actually 40 inches, and supply this period to the signal generator 180 to generate this signal.

As discussed above, it is possible to generate a signal for the other devices without using the signal from the wheel sensor 320. That is, the speed can be determined from the positioning system (e.g., GPS receiver 130) and the parameters of the desired signal can be sent to the signal generator so that a signal can be generated and distributed to the other systems, all without an actual wheel rotation sensor 320. This allows the system to serve as a back up for situations where the wheel sensor fails. This also allows the wheel sensor to be replaced, but such a system has the drawback that it will not provide a correct signal when the GPS system is not operational.

When a train is equipped with a wheel sensor such as a revolution counter, it may not be possible due to the way in which the sensor is configured to read the revolution count directly. Rather, such sensors automatically calculate a distance by multiplying the number of revolutions by the wheel size. Similarly, speed is calculated by dividing this distance over time. As the actual wheel size changes, the distance and speed calculated using a nominal wheel size will change by a proportional amount. One way in which to correct for this change is to substitute the actual wheel size for the nominal wheel size in the calculations discussed above (e.g., the DIP switches in the devices may be reconfigured to match the actual wheel size, or a memory that holds the wheel size may be updated with the actual wheel size as determined using any of the methods discussed herein).

However, it may not always be possible or practical to reconfigure the sensor with a new wheel size. Those of skill in the art will recognize that it is also possible to calculate correction factors that can be used compensate the speed or distance indicated by such sensors for wheel wear. These correction factors can be calculated with or without calculating the wheel size. For example, a correction factor can be calculated based on the actual wheel size (which may be determined using the methods discussed above) and the nominal wheel size used by the device. The correction factor may be, for example, a ratio of the nominal wheel size and actual wheel size. The speed/distance received from a sensor using the nominal wheel size is then multiplied by the correction factor. This technique is particularly useful when using wheel sensors that are not reconfigurable or that require manual reconfiguration (e.g., manually changing DIP switches or the like). Thus, for example, if the actual wheel size were 36 inches and the nominal wheel size used

by the device were 40 inches, then the correction factor would be 36/40 = 0.9. This correction factor is then stored and used to correct distance or speed from such a wheel sensor by multiplying it by 0.9. Again, the actual wheel size used in this technique can be determined using the methods discussed herein.

The correction factor can also be calculated without calculating the actual wheel size by comparing the distance or speed from a sensor using a nominal wheel size with a distance or speed from a positioning system. An exemplary method for calculating such a correction factor with the system of 100 of Figure 1 is illustrated in the flowchart 600 of Figure 6. At step 602, the control unit 110 consults the map database 140 to determine if the track conditions are favorable (similarly to step 210 of Figure 2). If the track conditions are not favorable at step 602, the control unit 110 delays for a period of time at step 604 and repeats step 602 until track conditions are favorable. In some embodiments, a minimum speed check (not illustrated in Figure 6) is also performed for the reasons discussed above. When track conditions are favorable at step 602, the control unit 110 determines a start position from the global positioning receiver 130 at step 606 and gets a corresponding start position from the wheel sensor at step 608. After delaying for a period of time at step 610, the control unit 110 gets the current position from the positioning system 130 at step 612. If the difference between the current position and the start position has not yet reached a threshold at step 614, step 612 is repeated. When the threshold has been reached at step 614, the control unit 110 determines a stop positions from the global positioning receiver 130 and the wheel sensor 120 at step 616. Next, at step 618, the control unit 110 calculates a correction factor by dividing the distance indicated by the positioning system

(which is the difference between the start and stop positions indicated by the positioning system at steps 606 and 616) by the distance indicated by the wheel sensor. Thus, if the positioning system indicates that the distance is 1.8 miles, and (due to wheel wear) the wheel sensor indicates that the distance is 2.0 miles, then the correction factor is 1.8/2.0 = 0.9. This correction factor is then stored and used to correct any speed or distance from the wheel sensor until the procedure of Figure 6 was performed again on a periodic basis to update the correction factor for additional wheel wear.

It should be understood that the above technique can also be used with the integration technique described above in connection with Figures 4 and 5. Those of skill in the art will recognize that the above-described technique may be modified to calculate the correction factor by comparing speeds (rather than distances) from the positioning system and wheel sensor.

Obviously, numerous modifications and variations of the present invention are possible in light of the above teachings. It is therefore to be understood that within the scope of the appended claims, the invention may be practiced otherwise than as specifically described herein.